



UNIVERSITI PUTRA MALAYSIA

**A METHODOLOGY FOR ASSESSING THE IMPACT OF LANDUSE
CHANGES ON WATERSHED RUNOFF**

MUSTAFA YOUSIF MOHAMED.

FK 2006 18

**A METHODOLOGY FOR ASSESSING THE IMPACT OF LANDUSE
CHANGES ON WATERSHED RUNOFF**

By

MUSTAFA YOUSIF MOHAMED

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia,
in Fulfilment of the Requirement for the Degree of Doctor of Philosophy**

January 2006



DEDICATION

***This work is dedicated to my family members
who are always giving me encouragement
and support***

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

**A METHODOLOGY FOR ASSESSING THE IMPACT OF
LANDUSE CHANGES ON WATERSHED RUNOFF**

By

MUSTAFA YOUSIF MOHAMED

January 2006

Chairman: Professor Ir. Mohd Amin Mohd Soom, PhD

Faculty: Engineering

With rapid land development and limited water resources, good quality water becomes an important commodity that every economic sector is competing for. Landuse changes in a watershed can affect the watershed hydrology in various ways. Some types of land development can be associated with increased impervious area causing increase in surface runoff and decrease in ground water recharge. Both of these processes can have large-scale ramifications through time. Increased runoff results in higher flows during rainfall events, which in turn increases the number of times that a river floods the adjacent land areas. Likewise, this increase in runoff and channel flows can drastically increase the erosion of river channel beds and banks, potentially destabilizing bridges or local structures. On the other hand the groundwater recharge decreased due to the increase in the impervious surfaces and decrease in the soil infiltration rate. This may leads to rescission in the river base flow especially during the dry season. Since rainfed agriculture in Malaysia may not have reservoirs for irrigation water supply, it is very important to maintain high base flows so that enough water is available for irrigation during the dry season. Understanding how the landuse change influences the river basin hydrology may

enable planners to formulate policies to minimize the undesirable effects of land development. The main objective of this study was to develop a methodology to assess the impacts of landuse changes on the watershed runoff. The need for spatial and temporal land-cover change detection over a larger scale makes satellite imagery the most cost effective, efficient and reliable source of data. The applicability of GIS makes it an important and efficient tool for spatial hydrologic modeling. In this study Satellite images and GIS were integrated with a developed spatial hydrological model to evaluate the impacts of land development in the Upper Bernam River Basin of Malaysia. The Bernam River is the main source of irrigation water for a rice granary area. A methodology to assess the hydrological impacts due to landuse modifications was developed using a physically based hydrological model and a mathematical model. While conceptual or physically based models are important in understanding hydrological processes, there are many practical situations where the main concern is with making accurate predictions at specific locations. The well-established HEC-1 model was calibrated and used to simulate the runoff process. Runoff hydrographs were generated for wet and dry seasons using lumped and distributed modeling concepts. In the distributed modeling approach, hydrographs from each sub basin was routed to the outlet point using the Muskingum routing method. Artificial Neural Network (ANN) model was developed because it has the ability to extract the non-linear relation between the inputs and outputs of a process, without the physics being explicitly provided to them, this makes the simulation process more applicable. The models were tested and validated using data collected from the study area. The models performances were checked using both graphical and statistical analysis. Mean absolute errors (MAE), mean square error (MSE), root mean square error (RMSE), Theil's coefficient, coefficient of determination (R^2),

coefficient of efficiency (E), T-test and regression analysis were used as evaluation criteria for model performance. The models show good performance in simulating the runoff process. Results from the hydrological model gave 0.79, 1.35, 0.22, 0.91 and 0.67 for MAE, MSE, U, R^2 and E, respectively. The weighted curve number (CN) was found to have increased by 2% in year 2001 compared to 1989, and had caused an increase in peak flow by 7%. The effect of change in CN is more on the rising limb of the hydrograph and peak runoff than on the falling limb. As CN increases the rising limb shifted backwards. For the ANN model, it was found that correlation coefficients between simulated and observed flow are 0.94 and 0.89 for the training and testing phases, respectively. The model outputs were within the confidence level of 95 %, and most of the scatter output values were within 15 % deviation bands. The statistical evaluation during the training phase gave the values of 0.001, 4.77, 0.06 and 0.87 for MAE, MSE, U and E, respectively, and these values were found to be 17.6, 5.6, 0.11, and 0.58 for the testing phase, respectively. For both models applications, it was found that the percentage change in runoff due to landuse change is constant for different landuse, irrespective of the rainfall pattern and time of occurrence. The models were then applied to simulate the runoff from future land development for the year 2020 and from different landuse scenarios. Predictions from the hydrological model show that an increase in weighted CN by 7 % and 13 % for the wet and dry seasons, respectively, will cause an increase in flow volume by 53 % and 62 % and increase in peak flow by 80 % and 76 % for the wet and dry seasons, respectively. This methodology can be applied for any future development plans to predict the hydrological impacts to mitigate the risk of floods occurrence and avoid the shortage of irrigation water. The methodology can be used as a decision making tool when formulating landuse policies. It can be a practical

tool for hydrologists, engineers and town and country planners. The irrigation engineers can use this tool during the planning for irrigation water supply and determination of future cultivable areas based on the availability of the irrigation water due to the land development.

Abstrak tesis yang dikemukakan kepada senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

**SATU KAEDAH UNTUK MENTAKSIR IMPAK PERUBAHAN
GUNATANAH KE ATAS AIR LARIAN LEMBANGAN**

Oleh

MUSTAFA YOUSIF MOHAMED

Januari 2006

Pengerusi: Profesor Ir. Mohd Amin Mohd Soom, PhD

Fakulti: Kejuruteraan

Dengan pembangunan tanah yang pesat dan sumber air yang terhad, air yang berkualiti baik menjadi komoditi penting bagi setiap sektor ekonomi. Perubahan kegunaan tanah di kawasan tadahan memberi kesan ke atas hidrologi kawasan tadahan dalam pelbagai cara. Beberapa jenis pembangunan tanah boleh dikaitkan dengan peningkatan kawasan lapisan penahan yang menyebabkan peningkatan air larian permukaan dan mengurangkan pengisian semula air bumi. Kedua-dua proses ini boleh mengakibatkan kemusnahan besar akhirnya. Hasil peningkatan air larian bagi aliran yang lebih besar semasa kejadian hujan sebaliknya meningkat kekerapan sungai akan membanjiri kawasan berhampiran. Sama dengan peningkatan air larian, aliran laju yang menghakis tebing mengakibatkan rutuhan tebing sungai yang berpotensi merosakkan jambatan atau binaan setempat. Dalam kata lain, pengisian semula air bumi merosot kerana peningkatan lapisan penahan permukaan dan mengurangkan kadar susupan tanah. Ini mungkin membawa kepada rosotan aliran asas sungai terutama semasa musim kering. Di kawasan jelapang padi yang tidak disediakan dengan empangan bagi membekal air pengairan, adalah amat penting bagi menjaga aliran asas tapak yang tinggi supaya bekalan air yang cukup dapat

disediakan bagi pengairan di musim kering. Kefahaman kesan perubahan kegunaan tanah ke atas hidrologi lembangan sungai adalah penting bagi para perancang dasar supaya mereka dapat mengurangkan kesan negatif pembangunan tanah. Tujuan utama kajian ini adalah untuk membangunkan kaedah anggaran kesan perubahan kegunaan tanah ke atas air larian kawasan tadahan. Keperluan mengetahui kesan perubahan liputan tanah secara ruang dan temporal bagi skala yang lebih besar membuat gambar satelit lebih memberangsangkan sebagai sumber data yang efisien dan benar. Keupayaan menggunakan GIS pula adalah sebagai alat penting dan berkesan bagi pemodelan hidrologi ruang. Dalam kajian ini, gambar satelit dan GIS telah digabungkan dengan model hidrologi ruang yang telah dibangunkan untuk menilai kesan pembangunan di kawasan tadahan hulu Sungai Bernam, Malaysia. Sungai Bernam adalah sumber utama bagi air pengairan di kawasan tanaman padi Tanjung Karang. Satu kaedah bagi menganggarkan kesan hidrologi yang disebabkan oleh perubahan kegunaan tanah telah dibangunkan dengan menggunakan model hidrologi berasaskan fisikal dan model matematik. Model koseptual atau model berasas fisikal adalah penting bagi memahami proses hidrologi, tetapi terdapat banyak suasana praktik yang mana penglibatan utama adalah kejituan anggaran bagi lokasi-lokasi tertentu. Model HEC-1 yang sedia ada telah dikalibrasikan dan digunakan bagi simulasi proses air larian. Hidrograf air larian telah diadakan bagi musim basah dan kering dengan menggunakan konsep longgokan dan pemodelan taburan. Dalam kaedah pemodelan taburan, hidrograf setiap tadahan kecil telah disalur ke titik alurkeluar menggunakan kaedah saluran Muskingum. Model rangkaian neural artificial (ANN) telah dibangunkan oleh kerana ia berupaya mengasingkan hubungkait yang bukan lurus di antara input dan output bagi satu proses, dengan tidak perlu memberi fizik yang jelas, ini menjadikan proses simulasi

lebih berupaya digunakan. Semua model telah disahkan dengan ujian menggunakan data dari kawasan kajian. Pelakuan model telah diperiksa menggunakan kedua-dua cara analisis grafik dan statistik. Mean Absolute Error (MAE), Root Mean Square Error (RMSE), U-Thiel's coefficient, coefficient of determination (R^2), coefficient of efficiency (E), T-test dan analisis regresi telah diguna sebagai syarat penilaian pelakuan model. Semua model menunjuk pelakuan yang baik dalam simulasi proses air larian. Hasil dari model hidrologi memberi 0.79, 1.35, 0.22, 0.91 dan 0.67 bagi MAE, RMSE, U, R^2 dan E, tersebut. Beratan nombor lengkung (CN) telah meningkat 2% bagi tahun 2001 berbanding 1989, dan menyebabkan peningkatan 7% aliran paling tinggi. Kesan perubahan CN adalah lebih banyak ke atas hidrograf cabang meningkat dan air larian yang paling tinggi berbanding ke atas cabang menurun. CN meningkat, cabang atas menurun. Bagi model ANN, koefisien korilasi di antara aliran simulasi dan yang benar adalah 0.94 dan 0.89 bagi fasa latihan dan ujian tersebut. Hasil output model adalah dalam lingkungan tahap kepercayaan 95% dan kebanyakan nilai output yang bertabur adalah dalam lingkungan jalur selisih 15%. Penilaian statistik semasa fasa latihan memberi nilai 0.001, 4.74, 0.06 dan 0.87 bagi MAE, RMSE, U dan E, dan nilai-nilai ini terdapat 17.6, 5.6, 0.11 dan 0.58 bagi fasa ujian. Bagi kegunaan kedua-dua model, peratus perubahan air larian yang disebabkan perubahan kegunaan tanah adalah sama bagi kegunaan tanah yang berbeza,. Cubaan simulasi air larian untuk pembangunan tanah di tahun 2020 bagi pelbagai skenario kegunaan tanah telah dibuat. Anggaran dari model hidrologi menunjukkan 7% dan 13% peningkatan beratan CN bagi musim basah dan kering akan menyebabkan peningkatan kadar aliran 53% dan 62%, dan meningkatkan aliran paling tinggi sebanyak 80% dan 76% masing-masing bagi musim basah dan kering. Kaedah ini boleh digunakan bagi mana-mana perancangan pembangunan di masa

depan untuk menganggar kesan hidrologi bagi mengurangkan risiko banjir dan mengelak kekurangan air bagi pengairan. Kaedah ini boleh diguna sebagai alat membuat keputusan ketika merancang pembangunan gunatanah. Ia boleh menjadi alat praktik bagi ahli hidrologi, jurutera dan perancang bandar dan desa. Jurutera pengairan boleh menggunakan teknik ini semasa penentuan kawasan pertanian dan merancang penjadualan air pengairan.

ACKNOWLEDGEMENTS

First of all I should thank the Almighty, for without His blessings it would not have been possible for me to do this study. I wish to extend my gratitude to my employer; the Alzaiem Alazhary University and the Sudan government through the Ministry of Higher Education, for granting me the financial support to enable me to pursue this study. Special thanks to Professor Ir Dr Mohd Amin Mohd Soom, who besides being my supervisor, tirelessly worked hard to ensure that I managed to complete study. His commitment all through my studies was overwhelming. I would also like to thank my other supervisory committee members, Assoc. Prof Ir Dr Lee Teang Shui and Assoc. Prof Dr Abdul Rashid Mohamed Shariff for their guidance and advice whenever I encountered problems in the course of my research. I would like to thank the Director of the Institute of Advanced Technology (ITMA) Universiti Putra Malaysia for providing me the use of the laboratory facilities of ITMA, also thanks to all staff of the SMART Farming Laboratory, ITMA for their cooperation. I would like to extend my thanks to the following organizations in Malaysia

- Malaysian Center for Remote Sensing (MACRES)
- Department of Irrigation and Drainage (DID)
- Department of Surveying and Mapping Malaysia (JUPEM)
- Department of Agriculture (DOA), Malaysia
- Department of country and town planning, Selangor
- Department of Biological and Agricultural Engineering, UPM

Last but not least I will never forget to thank my immediate family members especially my father who understood the need for me to be away for studies, my wife Amel Awad for her patience and encouragements and all friends and colleagues.


I certify that an examination committee has met on 16th January 2006 to conduct the final examination of Mustafa Yousif Mohamed on his Doctor of Philosophy thesis entitled "A Methodology for Assessing the Impact of Landuse Changes on Watershed Runoff" in accordance with Universiti Pertanian Malaysia (higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination committee are as follows:

Ir Desa Ahmad, PhD
Professor
Faculty Engineering
Universiti Putra Malaysia
(Chairman)

Shattri Mansor, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Abdul Aziz Zakaria, PhD
Lecturer
Faculty Engineering
Universiti Putra Malaysia
(Internal Examiner)

Salim Said, PhD
Professor
Faculty of Engineering
Universiti Malaysia Sarawak
(External Examiner)



HASANAH MOHD. GHAZALI, PhD
Professor/Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date : 27 MAR 2006

This thesis submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirements for the degree of Doctor of Philosophy. The members of the Supervisory Committee are as follows:

Ir. Mohd Amin Mohd Soom, PhD

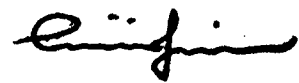
Professor
Faculty of Engineering
University Putra Malaysia
(Chairman)

Abdul Rashid Mohamed Sharif, PhD

Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Ir. Lee Teang Shui, PhD

Associate Professor
Faculty of Engineering
University Putra Malaysia
(Member)



AINI IDERIS, PhD

Professor/Dean
School of Graduate Studies
Universiti Putra Malaysia

Date : **13 APR 2006**

DECLARATION

I hereby declare that the thesis is based on my original work except for equations and citations, which have been duly acknowledged. I also declare that it has not been previously or currently submitted for any other degree at UPM or other institutions.



MUSTAFA YOUSIF MOHAMED

Date: 24-03-06

TABLE OF CONTENT

	Page
DEDICATION	ii
ABSTRACT	iii
ABSTRACK	vii
ACKNOWLEDGEMENTS	xi
APPROVAL	xii
DECLARATION	xiv
LIST OF TABLES	xviii
LIST OF FIGURES	xx
 CHAPTER	
 1 INTRODUCTION	 1
1.1 General	1
1.2 problem statement	2
1.3 The scope of the work	3
1.4 Hydrological modeling	4
1.4.1 Remote sensing and GIS in hydrological modeling	5
1.5 Artificial Neural network model (ANN)	7
1.6 Objectives	8
 2 LITERATURE REVIEW	 9
2.1 General	9
2.2 Effects of landuse change on watershed hydrology	10
2.3 Remote sensing applications in hydrological modeling	11
2.3.1 Landuse classification	13
2.4 GIS applications in the hydrological modeling	14
2.5 Digital terrain data for the hydrological modeling	17
2.5.1 Stream and watershed delineation based on digital terrain data	19
2.6 Evolution of Runoff Hydrograph Models	20
2.7 Computer-based hydrologic and hydraulic modeling	21
2.7.1 HEC-1 model	22
2.7.2 Watershed Modeling System (WMS) software	24
2.8 Base flow separation	25
2.9 Hydrological modeling approaches	26
2.9.1 Distributed modeling approach	27
2.9.2 Lumped modeling approach	29
2.10 Earlier works	29
2.11 Artificial Neural Network Modeling	31
2.11.1 The neuron and perceptron and their functions	35
2.11.1.1 Unsupervised learning	36
2.11.1.2 Supervised (Reinforcement) learning	36
2.11.1.3 Backpropagation	37
2.11.2 Multi-neural network	38
2.11.3 Hopfield network	38



2.12	Modeling the rainfall runoff process using ANN	39
2.12.1	Determination of model inputs	41
2.12.2	Data pre-processing	42
2.12.3	Determination of network architecture	43
2.12.4	Type of connection and degree of connectivity	44
2.12.5	Geometry	44
2.12.6	Choice of performance criteria	46
2.12.7	Optimization (training)	48
2.12.8	Post Training Analysis	52
2.12.9	Validation	53
2.12.10	Model Generalization Improvement	53
2.13	Review summary	55
3	METHODOLOGY	58
3.1	The study site	58
3.2	Data	60
3.3	Precipitation and runoff data analysis	61
3.3.1	Rainfall probabilities and return period calculations	61
3.3.2	Base flow separation	62
3.4	Statistical criteria used for models evaluation	63
3.5	Artificial neural network model (ANN)	64
3.5.1	Selection of model inputs and outputs	65
3.5.2	model structure	66
3.5.3	Improving the model generalization	67
3.5.4	Post training analysis	68
3.6	Hydrological modeling	69
3.6.1	The SCS Curve Number Method	69
3.6.2	Landuse parameter	70
3.6.3	Hydrological Soil Groups (HSG)	72
3.6.4	Digital Elevation Model (DEM)	73
3.6.5	Rainfall-Runoff Simulation	74
3.6.5.1	Flood routing	77
3.7	Landuse- peak flow Model (LPM)	79
3.7.1	LPM Model application	80
4	RESULTS AND DISCUSSIONS	82
4.1	Precipitation and flow data analysis	82
4.1.1	Rainfall and flow data consistency	83
4.1.2	Return periods and frequencies analysis	87
4.1.3	Base flow separation	90
4.2	Artificial neural network molding	90
4.2.1	Determination of the ANN model parameters	91
4.2.2	Model structure	92
4.2.3	Network training process	93
4.2.4	Post training analysis	95
4.2.5	Assessment of the impacts	100
4.2.7	ANN model limitation	106
4.3	Distributed and lumped hydrological modeling approaches	106
4.3.1	Distributed hydrologic modeling (DHM)	110
4.3.1.1	Daily flow simulation	116

4.3.2	Lumped modeling approach (LM)	131
4.3.3	Assessment of the impacts	144
4.3.3.1	Impacts on the runoff volume	147
4.3.3.2	Impacts on the peak flow	149
4.3.3.3	Impacts on the time to peak flow	151
4.3.3.4	Impacts on the sub basins level	152
4.3.3.5	Lag time (travel time) analysis	154
4.3.4	DHM Model applications	156
4.4	Landuse - peak flow model (LPM)	161
4.4.1	LPM Performance	163
4.4.2	LPM applications	165
4.5	Comparison of ANN and DHM models performance	168
5	SUMMARY, CONCLUSIONS AND RECOMMENDATIONS	170
5.1	Summary	170
5.2	Conclusions	171
5.3	Recommendations	172
	REFERENCES	174
	APPENDICES	184
	BIODATA OF THE AUTHER	210

LIST OF TABLES

Table	Page
2.1 Radiometric Characteristics of the TM Sensors	12
2.2 Hydrological models compatible with GIS	23
2.3 Learning functions and their description	50
3.1 TM Images description	71
3.2 HSG Characteristics	73
3.3 Rainfall Stations	76
4.1 Weights of the rainfall station from Thiessen polygons	84
4.2 Annual flow form the watershed outlet	85
4.3 Monthly means of rainfall and runoff data	86
4.4 Descriptive statistics for rainfall and runoff data	87
4.5 Rainfall probability and return period calculations	88
4.6 Training parameters	94
4.7 Statistical analyses results of the model performance	99
4.8 Results of Regression Analysis	100
4.9 Percentage of landuse areas	103
4.10 Sub basins parameters	110
4.11 Weighted CN for the sub basins for the different years	114
4.12 Statistical test results for DHM during the dry season	123
4.13 Statistical test results for DHM during the wet season	129
4.14 Composite Curve Number	131
4.15 Lumped model performance	136
4.16 Comparisons between the models performance	137
4.17 Changes in runoff volume due to change in landuse	147

4.18	Percentage Changes in runoff volume due to change in landuse	148
4.19	Changes in peak flow using different rainfall pattern	150
4.20	Hydrological changes on the sub basins level	153
4.21	Impacts on the lag time during the dry season	155
4.22	Impacts on the lag time during the wet season	155
4.23	Changes in CN for the years 2020 and 2001	158
4.24	Changes in the lag time due to the future landuse plan	161
4.25	Results of the Statistical analysis for LPM	165
4.26	Differences between the LPM and DHM results	167
4.27	Compression of ANN and DHM models performance	168

LIST OF FIGURES

Figure	Page
2.1 The biological Neuron	33
3.1 Location of the study area	59
3.2 Watershed modeling process	75
3.3 The methodology flow chart	81
4.1 Locations of the rainfall stations	83
4.2 Mass curve analyses for the flow data	85
4.3 Long term rainfall-runoff pattern	86
4.4 Probability analyses for the annual rainfall	89
4.5 Return period for the rainfall events	89
4.6 Base flow separations for April 1989	90
4.7 ANN model structure	93
4.8 Observed and simulated flow during the training phase	95
4.9 Observed and simulated flow during the testing phase	96
4.10 Best linear fit of the model during the training phase	96
4.11 Best linear fit of the model during the testing phase	97
4.12 Scattered points for the training phase	98
4.13 Scattered points for the testing phase	98
4.14 Landuse map for the year 1989	101
4.15 Landuse map for the year 1993	101
4.16 Landuse map for the year 1995	102
4.17 Landuse map for the year 1998	102
4.18 Landuse map for the year 2001	103
4.19 Percent change in the runoff amount from rainfall amounts	104

4.20	Change in runoff amount due to change in landuse	105
4.21	Landuse distributions through the years	108
4.22	Hydrological soil groups (HSG)	108
4.23	Drainage systems for the study area	109
4.24	Watershed sub basins	110
4.25	HSG distributions within the sub basins	111
4.26	Built-up area distributions on the sub basins level	111
4.27	Oil palm trees area distributions on the sub basins level	112
4.28	Forest area distributions on the sub basins level	112
4.29	Rubber trees area distributions on the sub basins level	113
4.30	Change in curve number in the sub-basins level	114
4.31	Stream network for routing	116
4.32	Model performances using a dry season event of 10 Jan. 1989	117
4.33	Model performance using a dry season event of 7 Feb. 1993	117
4.34	Model performance using a dry season event of 24 Feb. 1989	118
4.35	Model performance using a dry season event of 4 Mac.1989	118
4.36	Model performance using a dry season event of 30 Mac. 1993	119
4.37	Model performance using a dry season event of first June 1993	119
4.38	Model performance using a dry season event of 3 June 1989	120
4.39	Model performance using a dry season event of 18 June 1989	120
4.40	Model performance using a dry season event of 23 June 1993	121
4.41	Model performance using a dry season event of 6 July 1993	121
4.42	Model performance using a dry season event of 3 August 1989	122
4.43	Model performance using a dry season event of 26 August 1993	122
4.44	Model performance using a dry season event of 8 Dec. 1989	123

4.45	Model performance using a rainy season event of first April 1989	124
4.46	Model performance using a rainy season event of 4 April 1989	124
4.47	Model performance using a rainy season event of 21 April 1993	125
4.48	Model performance using a rainy season event of 30 April 1989	125
4.49	Model performance using a rainy season event of 8 May 1993	126
4.50	Model performance using a rainy season event of 17 May 1989	126
4.51	Model performance using a rainy season event of 2 Sep. 1993	127
4.52	Model performances using a rainy season event of 26 Sep. 1989	127
4.53	Model performance using a rainy season event of 24 Oct. 1993	128
4.54	Model performance using a rainy season event of 2 Nov. 1989	128
4.55	Model performance using a rainy season event of 24 Nov. 1993	129
4.56	Model performances in wet and dry season	130
4.57	Model performance using dry season event of 10 January	132
4.58	Model performance using dry season event of 24 February	132
4.59	Model performance using a dry season event of 4 March	133
4.60	Model performance using wet season event of first April	133
4.61	Model performance using dry season event of 18 June	134
4.62	Model performance using dry season event of third August	134
4.63	Model performance using wet season event of 26 September	135
4.64	Model performance using wet season event of second November	135
4.65	Model performance using dry season event of 8 December	136
4.66	Determination coefficient analysis for DHM and LM	138
4.67	MAE analysis for DHM and LM	138
4.68	RMSE analysis for DHM and LM	139
4.69	U Theil's coefficient analysis for DHM and LM	139

4.70	Coefficient of efficiency (E) analysis for DHM and LM	140
4.71	Peak flow from different modeling approaches	140
4.72	Impacts of landuse change using rainfall event from month of April	144
4.73	Impacts of landuse change using rainfall event from month of May	145
4.74	Impacts of landuse change using rainfall event from September	145
4.75	Impacts of landuse change using rainfall event from October	146
4.76	Impacts of landuse change using rainfall event from November	146
4.77	Impacts of landuse changes on the runoff volume	148
4.78	Changes in runoff volume due to the changes in CN	149
4.79	Impacts of landuse change on the peak flow	150
4.80	Change in peak runoff due to change in CN	151
4.81	Impacts on the time to peak flow	152
4.82	Hydrological changes in sub basin number 10	153
4.83	Landuse map for the year 2020	157
4.84	Impacts of future landuse on the runoff hydrograph (wet season)	158
4.85	Impacts of future landuse on the runoff hydrograph (dry season)	159
4.86	Change in flow volume for the future landuse plan	159
4.87	Change in peak flow for the future landuse plan	160
4.88	linear relationships between the changes in CN and peak flow	162
4.89	Performance of the LPM during the wet season	164
4.90	Performance of the LPM during the dry season	164
4.91	Comparison between LPM and DHM for dry season applications	166
4.92	Comparison between LPM and DHM for wet season applications	166
4.93	Differences in the LPM and DHM results	167

CHAPTER 1

INTRODUCTION

1.1 General

Water is a prime natural resource, a basic human need and a precious national asset. The extent to which water is abundant or scarce, clean or polluted, beneficial or destructive has a major influence on our planet in its rapidly changing face brought about by rapid development on all fronts, ever increasing population and fast rate of scientific and technological advancements.

Deforestations, urbanization, and other land-use activities can significantly alter the seasonal and annual distribution of stream flow within a watershed (Dunne and Leopold, 1978). It is likely that such changes can also affect the seasonal and annual distribution of base flow. Understanding how these activities have influenced stream flow pattern may enable planners to formulate policies to minimize the undesirable effects of future landuse changes.

Due to the land development, land covers are subjected to changes. Many watersheds and river basins soils are converted to impervious surfaces which lead to decrease in the soil infiltration rate and consequently increase the amount and rate of runoff. A lot of water makes its way to the sea during the rainy season due to the higher runoff. Since rainfed agriculture in Malaysia may not have reservoir for irrigation water